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Linking Human Activities to Water Quality in Coastal New England: Past and Present

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Linking Human Activities to Water Quality in Coastal New England:
Past and Present

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Abstract

This project examines the timing and effect of direct and indirect anthropogenic and natural influences on the marine environment in embayments in southern New England over the past decades to century timescale. We investigated the effects of human land use from colonial through post-industrial times, determined baseline conditions and natural climatic variability, and analyzed the response of marine ecosystems to specific local management actions aimed to improve water quality. A coastal sediment core was taken in Mumford Cove, CT and was analyzed downcore for eutrophication markers (C: N, %C, %N, $\delta^{15}\text{N}$, $\delta^{13}\text{C}$) and metals (Hg, Pb, Cu, and Zn). Analyses used include Elemental Analyzer/Isotope Ratio Mass Spectrometry (EA/IRMS) for eutrophication markers, X-Ray Fluorescence (XRF) and Mercury Analyzer for metals, and archival research to obtain relevant local histories. Our results suggest major ecosystem shifts that track across all measurements, indicating that sediment geochemistry is able to faithfully record both direct and indirect anthropogenic influences.

Acknowledgments

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Introduction

Coastal ecosystems are subject to changes forced by a variety of influences, ranging from natural to human events, from the local to regional scale. Natural events, such as hurricanes, can transform and modify coastal morphology through erosion and redeposition, as well as by ravaging coastal property and landscapes. Local and regional changes can include shifts in land-use practices, waste-management strategies, and legislations.

Sediment cores reflect both the stratigraphic records and sediment composition and persist as some of the best reservoirs of information regarding how the marine ecosystem has been affected and altered by natural and anthropogenic influences over time (Canuel, 2017). They can be used to reconstruct past water and sedimentary conditions, including eutrophication, hypoxia, and anoxia events (Cooper S. R., 1993). Excessive nutrient inflow (eutrophication) (Varekamp J. C., 2010), is the dominant anthropogenic contributor to hypoxia (Cooper S. R., 1993). Additional human influences in New England that span back to the colonial times are the impact of agriculture and infrastructure on waterways through dams, deforestation, water pollution (Köster, 2007), and more recent efforts following the Clean Water Act intended to restore water quality.

Previous studies across the east coast of the United States have found an increase in environmental degradation

over the last 200 years as settlements transitioned from pastoral to colonial, then from colonial to industrial and eventually post-industrial times (Varekamp J. C., 2010). Clear-cutting of the land is reflected in changes in sedimentation rate and composition. Organic matter with terrestrial vs. marine origins can be distinguished through analysis of their carbon to nitrogen ratio (C: N), in conjunction with the signature of the stable isotopes of N and C ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) (Varekamp J. C., 2010).

In the late 19th century, a shift in lithology from more inorganic fluvially derived sediments, followed by a rapid increase in the concentration of heavy metals, such as lead (Pb) and mercury (Hg), coincides with the growing popularity of along-river industrial activities (Woodruff, 2013). In addition to being used in industrial production, lead was also a common ingredient in gasoline from the mid- 1920s to the early 1970s, resulting in a sixfold increase in lead concentration during this period (Benoit, 1999). The average concentration of these metals and nutrient pollution has slowly decreased over time since the 1970s, due to the emergence of the Environmental Protection Agency (EPA) and the establishment of policies, such as the Clean Water Act (1972).

The goals of this study were to (i) understand whether sediment geochemistry faithfully records natural and human effects on coastal embayments,

and (ii) examine the relationship between natural resource quality and the values of adjacent populations.

Study Site

Mumford Cove is a relatively shallow embayment in Groton, CT (Figure 1). It is approximately 1 km across its opening to Long Island Sound (measured from Mumford Point to the end of Groton Long Point) and narrows to a width of 150 m at its head, where it is crossed by an Amtrack railroad causeway.

We chose to Study Mumford Cove for a number of reasons relating to its history and location. The first of which is that it is a good model system that is naturally sheltered because of its proximity to Fishers Island and location within Long Island Sound. There is also robust documentation of local history going back to the colonial era, in addition to records of ecosystem shifts directly linked to anthropogenic inputs. Lastly, Mumford Cove is similar to other systems where further work can be done.

Local History

It is important to first understand what sorts of changes were occurring on land around Mumford Cove before discussing how these may have influenced the sediment record.

Mumford Cove lies within the Town of Groton in New London County, Connecticut. Groton was founded in 1705 after it separated from the City of New London. In a similar fashion to the

surrounding region, its economy was primarily agricultural-mercantile based with a focus on the rearing and trading livestock at port (Kirmmse, 1981). However, the focus of Groton's economy began to shift over the course of the 19th Century, and by the turn of the 20th Century, Groton's economy was dominated by the manufacturing industry. By the end of World War II in 1945, Groton's industry began to specialize in submarine and chemical manufacturing with the arrival of the Electric Boat division of General Dynamics and Pfizer Inc., respectively (Becker, et al., 1977). The arrival and operation of these two companies, in addition to the United States Submarine Base and the United States Coast Guard Training Station, led to a rapid growth in population as new employees and their families moved to the area (Committee, 2003). This increase in population led to a higher demand for housing and infrastructure, prompting new housing developments, roads, and wastewater facilities.

In 1945, the Town of Groton opened a new wastewater treatment plant which discharged effluent into Fort Hill Brook, the primary tributary into

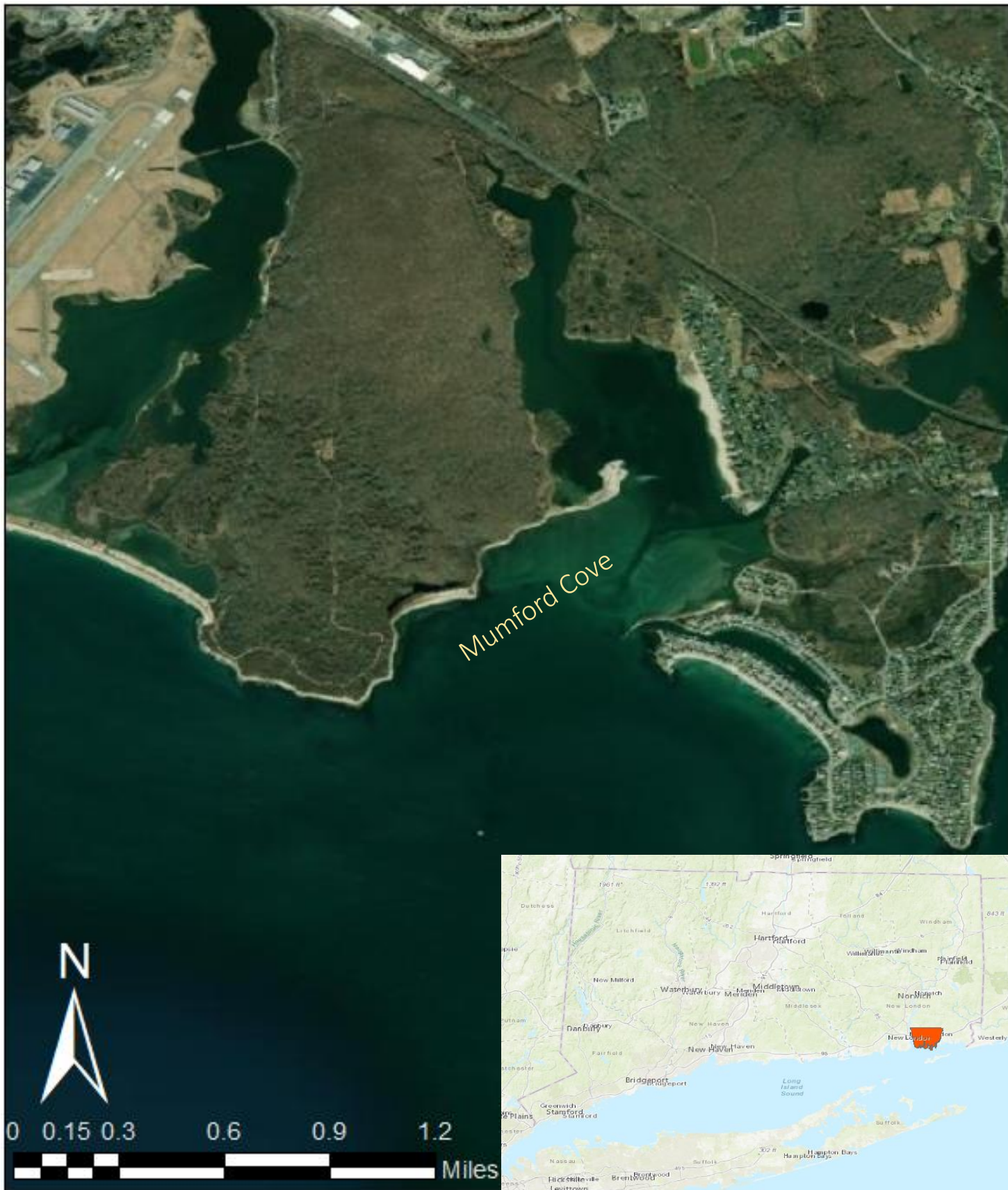


Figure 1: Map of Study site, Mumford Cove in Groton, CT. The inlaid regional map highlights Groton, CT (red) in relation to coastal Connecticut and parts of New York and Rhode Island.

Mumford Cove. As the population of Groton continued to grow, so did the volume of wastewater treated at the plant. In 1974, a larger wastewater treatment plant replaced the older plant, facilitating the processing of nearly one million gallons sewage daily by 1975. This increase in wastewater effluent transformed Mumford cove from a tidal saltwater embayment into a brackish body of water, choked by algae (Mumford Cove Ass'n v. Town of Groton, 1986). One homeowner adjacent to Mumford Cove referred to the water as resembling "spinach soup, [with an] atrocious stench in August" (Sandy, 2007). Other

homeowners banded together and sued the Town in 1986 under citizens suit-provisions of the Clean Water Act (1972). Finally in 1987, wastewater discharge from the wastewater treatment plant was diverted away from Mumford Cove. Algal blooms persisted for the following years until samples indicated normal, non-eutrophic nutrients and O₂ in 1989 (French, Harlin, Rines, & Puckett, 1989). Water quality became good enough that eelgrasses, whose populations had been decimated in the 1930s due to Wasting Disease, have slowly been able to recover and repopulate Mumford Cove (Sandy, 2007).

Methods

A 43 cm hand-push sediment core was retrieved at (41 deg, 19.795 min; -072 deg, 01.302 min) within the back bay of Mumford Cove (Figure 2) in September 2020. The core was sectioned at 1 cm intervals, which were then freeze dried. Bulk objects, such as stones larger than 0.25 cm and shells, were then removed and the samples were homogenized using a mortar and pestle in preparation for geochemical analyses. These can be characterized into three categorized based on what information they provided: sediment age, industrial activities, and ecosystem changes.

Age

An age model for our core was obtained through radioisotope analysis

and gamma spectroscopy. Analyses of powdered samples at every other depth interval was conducted in the laboratory of Dr. James Kaste at the College of William and Mary. Analysis was conducted following the procedures outlined by (Benoit, 1999) (Woodruff, 2013).

Industry

The influence of industry on Mumford Cove was analyzed through the quantification of heavy metal concentrations in each strata of pulverized sediments. Lead (Pb), Copper (Cu), and Zinc (Zn) concentrations were analyzed using a portable X-Ray Fluorometer (pXRF) in the Ouimet Lab in the Department of Geoscience at the University of Connecticut Storrs campus. Mercury (Hg) concentrations were

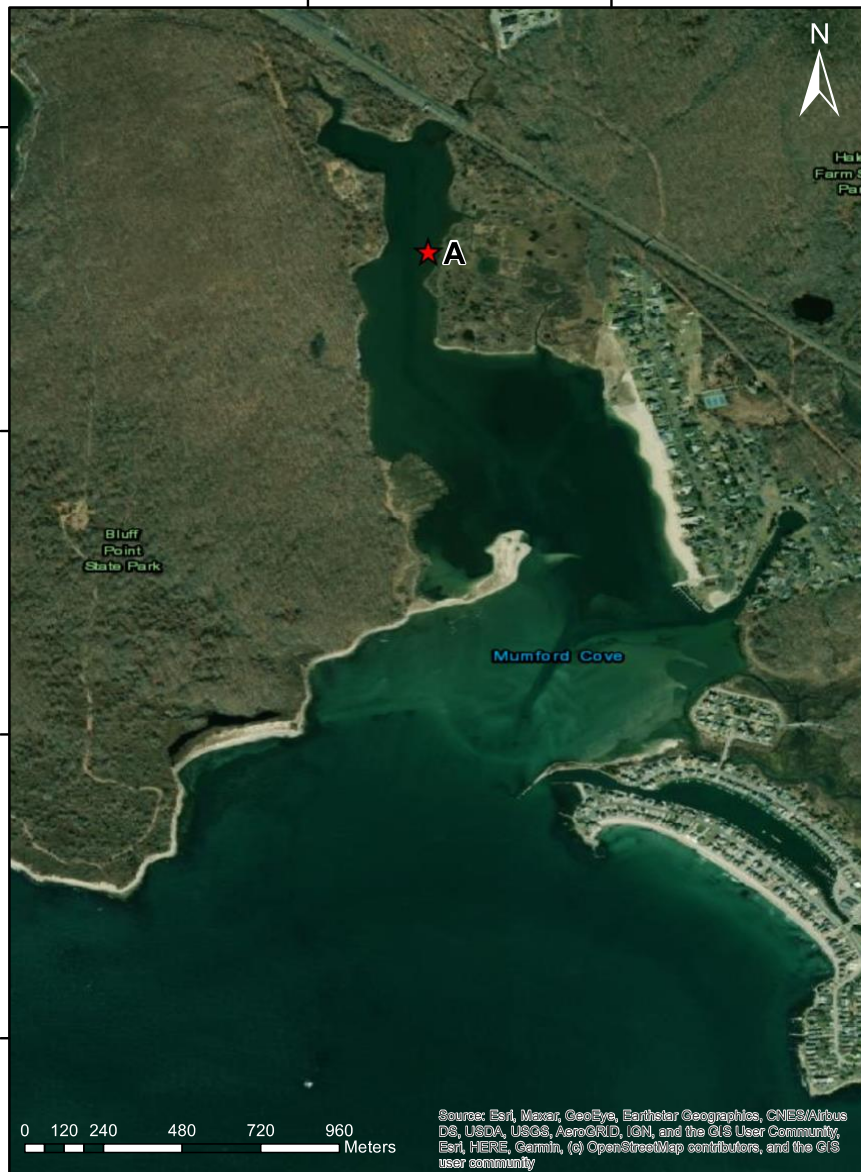


Figure 2: Map of Mumford Cove depicting the location of the study core, marked with a red star and is labeled 'A'.

measured using a Mercury Analyzer in the Mason Laboratory at the UConn Avery Point Campus.

Ecosystem Changes

Ecosystem changes were examined through a combination of analyses of carbon and nitrogen proxies, including

stable isotopes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$), percent of each species (%C and %N) and the ratio between carbon and nitrogen (C: N). These analyses were conducted on an Electron Analyzer/ Isotope Mass Spectrometry (EA/IRMS) in the Tobias Laboratory at the UConn Avery Point Campus.

Sample preparation for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, %N, and C: N involved weighing each sample with duplicates into tin capsules. Each capsule was then folded into a small sphere enclosing the sample, which was then loaded onto the wheel of the EA/IRMS equipment for analysis. Standards of 200–600 μg USGS 40 and 41 were also run along with the samples to provide a means for correction.

Sample preparation for %C samples followed a similar procedure, but with slight variation. Sediments from every other interval were weighed into silver capsules. Duplicates were created for every other stratum selected. Without closing the capsules, samples were exposed to acid. The purpose of this step was to react and eliminate inorganic carbon from the samples, allowing us to quantify the quantity of organic sample in

each sample. Following acidification, the capsules were sealed and run along with USGS 40 and 41 standards following the same procedure as outlined in the previous paragraph.

Cultural Shifts

Archival research was the primary avenue for data acquisition and involved both online resources and those in print at the Groton Public Library's History Room. The sources found can be split into three major categories:

1. Management and conservation plans/reports. These sources were primarily found in print through the History Room. Examining the issues discussed, authorship, and who these reports were commissioned/supported by provides insight into how much value is placed on natural resources by the population on both the local and greater regional/national level.
2. News and opinion pieces. These sources present direct accounts of current events throughout the years. Opinion pieces include blog posts, online forums, and pamphlets found in the History Room. These sources directly

reflect the opinions of the local population over time.

3. Aerial photographs of the Mumford Cove and the surrounding area. Aerial photographs are available through the University of Connecticut Library's MAGIC (Maps & Geographic Information Center). The first photograph available for the study site is from 1934, and this area was periodically photographed approximately once per decade throughout the remainder of the 20th Century to present day (the most recent photograph is from 2016). This series of photographs provides an illustrated timeline which visually depicts shifts in land-use across the 20th Century. Major shifts, including the abandonment of agriculture, urbanization, industrialization, and reforestation are represented in these photographs. This resource provided further, visual evidence for how local values changed over time to include more open spaces.

In addition to the above categories of sources, population data was referenced from the U.S. Census Bureau decadal survey compiled by the CT Office of Secretary of the State.

Results

Age

The age model for the core yielded a time range of approximately 225 years with a mean accumulation rate of 1.9 mm/year. Activity data for ^{210}Pb revealed that the upper 23 cm of the core span from 1931 to 2020. These dates were corroborated by ^{137}Cs activities, which were consistent with onset and peak in the late 1950s (Woodruff, 2013).

A steady accumulation model was applied to the data, which allowed us to extrapolate ages for strata below our 23 cm sample, resulting in a bottom-core date of approximately 1794 (Figure 3). Subsequent radioisotope analyses for the 29-30 cm, 35-36 cm, and 41-42 cm samples lacked detectable ^{137}Cs , with ^{210}Pb that was entirely supported by ^{226}Ra in the samples. This new data supports our extrapolated dates and increases our confidence in our age model.

Industry

The trend for our metals concentrations tracked similarly across all species analyzed (Hg, Cu, Zn, and Pb). Background concentrations are maintained by all metals until the 1930s,

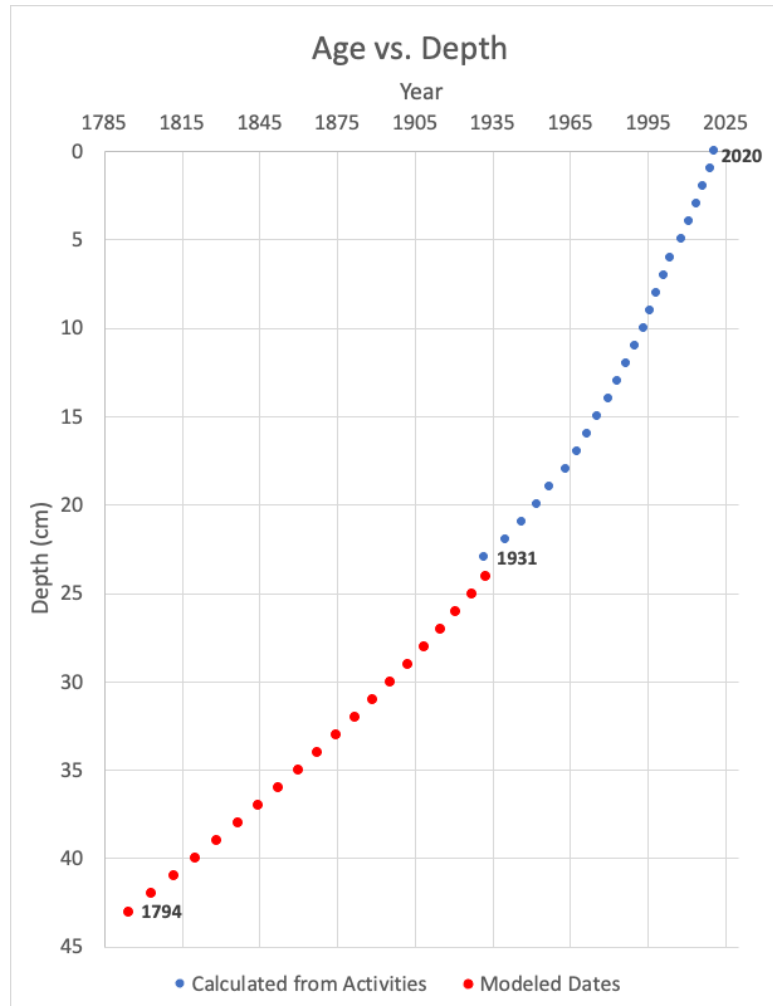


Figure 3: Plot of Age (year) vs. Depth (cm). Blue points represent ages calculated directly from radioisotope activities. Red points represent extrapolated dates found using a steady state accumulation model.

when the concentrations of all begin to increase (Figure 4). The rate of concentration increase of all metals appear to taper off in the 1970s and remains consistent for the following years up through the early 2000s.

Our profiles are consistent with past profiles (Varekamp J. K., 2003) (Benoit, 1999). However, our results appear to be muted both in terms of magnitude and temporally.

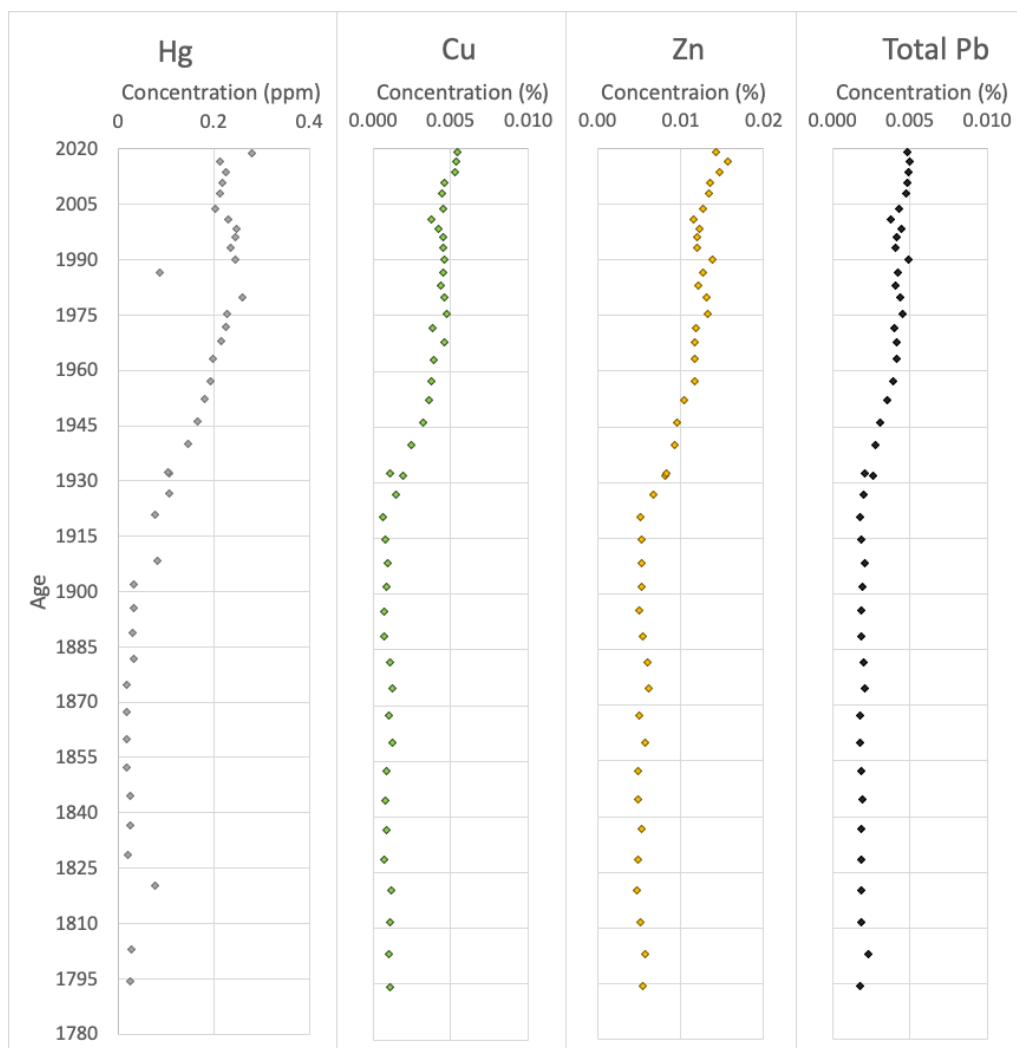


Figure 4: Metals Data. Graphs depict the concentrations of Mercury (Hg), Copper (Cu), Zinc (Zn), and Lead (Pb) over time, listed from left to right respectively.

isotope, $\delta^{13}\text{C}$, shows steady depletion of between 2–3 per mil from the 1930s until the 2000–2005 time period, after which values rebound slightly and trend toward more historic values. However, the magnitude of this shift is not as large as the initial change following the 1930s. C: N data shows a similar trend, where values

Ecosystem Changes

Analysis of carbon and nitrogen proxies for ecosystem change were divided into two groupings, (i) $\%C$, $\delta^{13}\text{C}$, and C: N, and (ii) $\%N$ and $\delta^{15}\text{N}$.

For group (i), all measures appear to remain relatively stable until the 1930s. Following this decade, $\%C$ in the system increases by approximately 2 percent, and remains around this quantity until present day. Analysis of the carbon stable

decrease following the 1930s, but begin to trend back toward historical values following 2005. Again, the post-2005 shift is of a smaller magnitude than the post-1930s shift. Since C: N and $\delta^{13}\text{C}$ begin to trend back toward historic values, but $\%C$ does not, this implies that there may be some other factor(s) to take into consideration.

Group (ii) data may help explain the difference in the modern record of the carbon proxies analyzed. Both $\delta^{15}\text{N}$ and

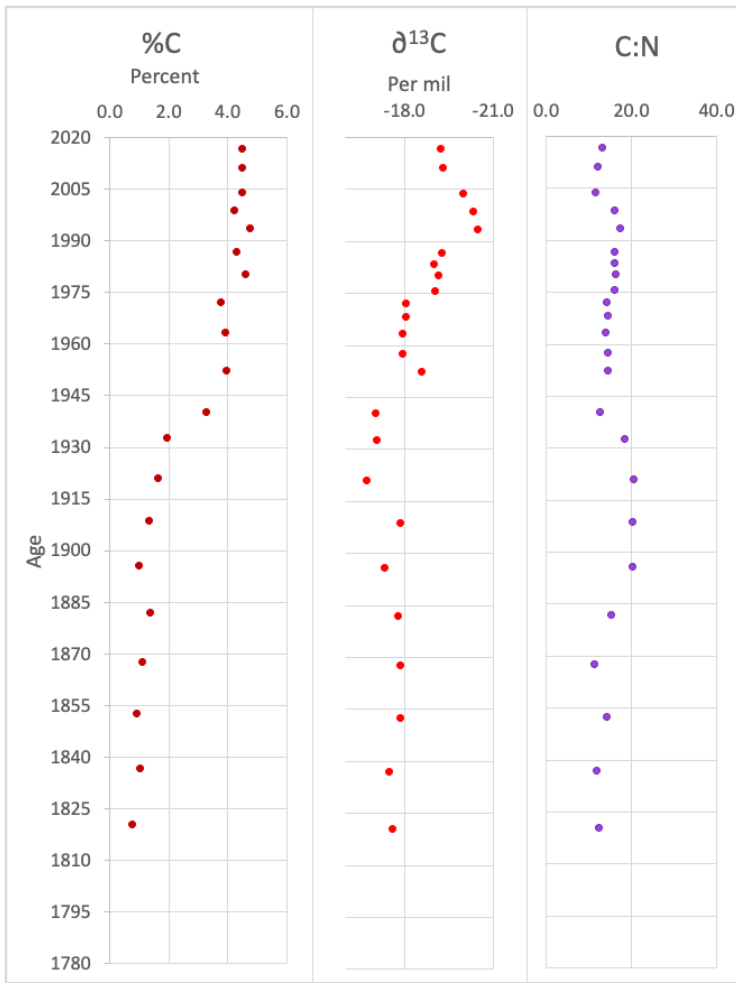


Figure 5: Plot of Carbon Proxy Data (%C, $\delta^{13}\text{C}$, C: N) downcore. Shifts occur at around the same depths/years, which provides evidence for ecosystem changes. Notable shifts occur in the 1930s and more subtly following the 2000–2005 timeframe.

%N records exhibit shifts in the mid-late-1930s into early 1940s. The nitrogen stable isotope, $\delta^{15}\text{N}$, shows signs of enrichment by approximately 1 per mil over a period of nearly 50 years. This enrichment occurs in distinct bursts, first from the late-1930s/early-1940s, then another one in the mid-1970s. In the 1980s, $\delta^{15}\text{N}$ appears to stabilize at around 5 per mil, which is approximately 1 per mil higher than the pre-1930s average. The %N profile exhibits shifts at around the same timeframes. However, the initial

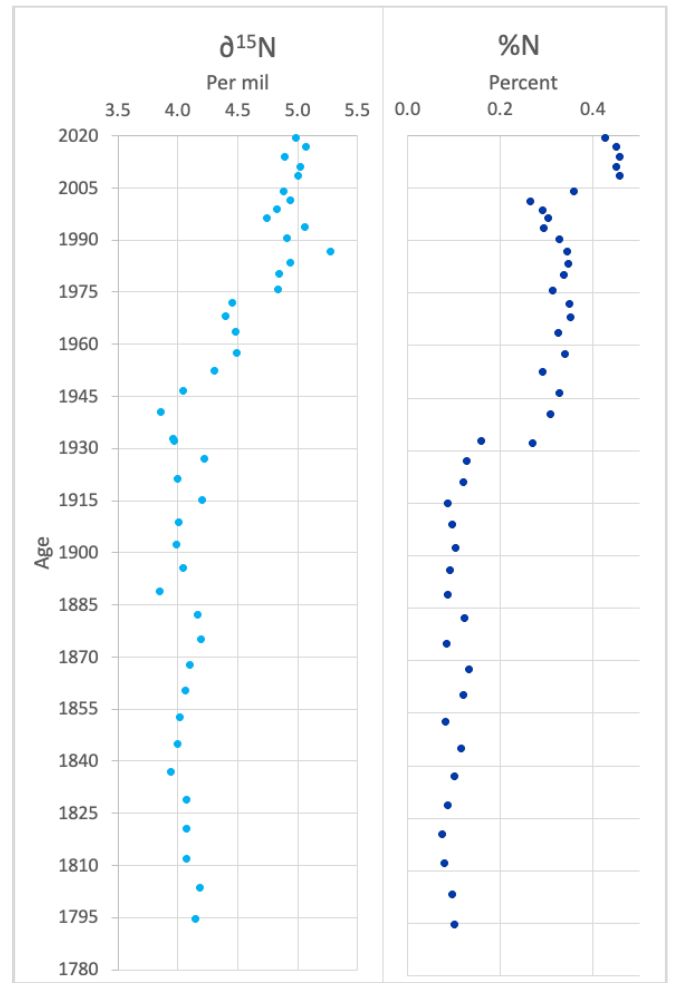


Figure 6: Plot of Nitrogen proxy data ($\delta^{15}\text{N}$, %N) downcore.

shift in the 1930s in of a greater magnitude than subsequent shifts in the 1970s. Unlike the $\delta^{15}\text{N}$ record, there appears to be an additional shift in more recent years (2005–present).

Cultural Shifts

The timeline of our Mumford Cove core captures the local and regional transition from an agricultural-mercantile to manufacturing economy. Aerial photographs throughout the 20th century and into the 21st century illustrate the

abandonment of agricultural lands and the spread of urbanization and industrial facilities (Appendix A). New manufacturing jobs attracted a new labor force, primarily young males and their families (Becker, et al., 1977). This influx of workers and their families accelerated urbanization and population growth (The Office of Secretary of the State Denise W. Merrill) (The United States Census Bureau, 2020). Comparison of our geochemical proxy profiles with population data reveals a striking similarity between their temporal records. This suggests that the sediments in Mumford Cove at the site of our core are recording a strong signal of localized effects (Figure 7).

The 1960s saw the rise of environmental advocacy and grassroots movements both locally and on the national level. For instance, in 1961, hundreds of Groton residents wrote letters and signed petitions opposing a zoning change that would have allowed developers to convert Haley Farm into apartment housing. The Groton Open Space Association (GOSA) was founded in 1967 by concerned citizens who wished to push for further protection of Haley Farm and other open spaces (Mancini, 2011). Under GOSA, the “Save the Haley Farm” movement took hold of the town with the objective of raising enough funds to purchase and convert Haley Farm into a state park. From 1965–1970, bake sales, concerts, and more were able to raise \$50,000. With \$100,000 contribution from the State, and \$150,000 from the federal government under the Land and Water Conservation Fund (LWCF), Haley Farm

became a State Park (Mancini, 2011) (Gosainc, 2000). Across the Cove from Haley Farm, similar conservation efforts were under effect, and in 1974, Bluff Point became a State Park and Coastal Reserve (Becker, et al., 1977). Haley Farm and Bluff Point are important cases to examine because their protection required intense social involvement, and the attention of multiple levels of government, thus reflecting the perceived value of natural resources. Additionally, management actions for these open spaces directly impacts Mumford Cove, as they lie within the Mumford Cove watershed (Appendix B) (DEP Natural Resource Center, 1974).

Policy often reflects the needs and desires of constituents, so it should be no surprise that the late 1960s and early 1970s gave rise to many environmental regulations on local, state, and federal levels. The Environmental Protection Agency (EPA) was created in 1970 as the regulating body for environmental programs (Kepner, 2016). In the same year, congress passed the Clean Air Act, which created air quality standards, in addition to phasing out leaded gasoline (U.S. Energy Information Administration, 2020). A couple of years later in 1972, the Clean Water Act was passed with the goal of regulating the discharge of pollutants into waterways and establishing standards for water quality (Environmental Protection Agency, 1972).

In 1971, just one year after the formation of the EPA, Connecticut’s General Assembly created the Department of Environmental Protection (CT DEP), a new state agency with two major goals:

outdoor conservation, and protection of the quality of Connecticut's natural resources (Connecticut Department of Energy and Environmental Protection, 2019). Other relevant legislations passed by the Connecticut General Assembly include the Inland Wetlands and Watercourses Act (IWWA) in 1972, Bluff Point Coastal Reserve Act in 1975, and Public Act 490 (Becker, et al., 1977) (Groton Conservation Commission, 1990). The IWWA produced a regulatory process that seeks to balance economic growth and ecological needs (CT DEEP, 2020),

while the Bluff Point Coastal Reserve Act provided legal protection to Bluff Point and its resources (Becker, et al., 1977). Public Act 490 took a different approach at protecting natural resources and open spaces. It provides tax incentives to owners of land with farm, forest, or open space, and allows their property to be appraised at its use value rather than at market value. This typically results in lower property taxes, allowing these spaces to persist and dissuades landowners from selling their property to developers and/or intensifying their land-use

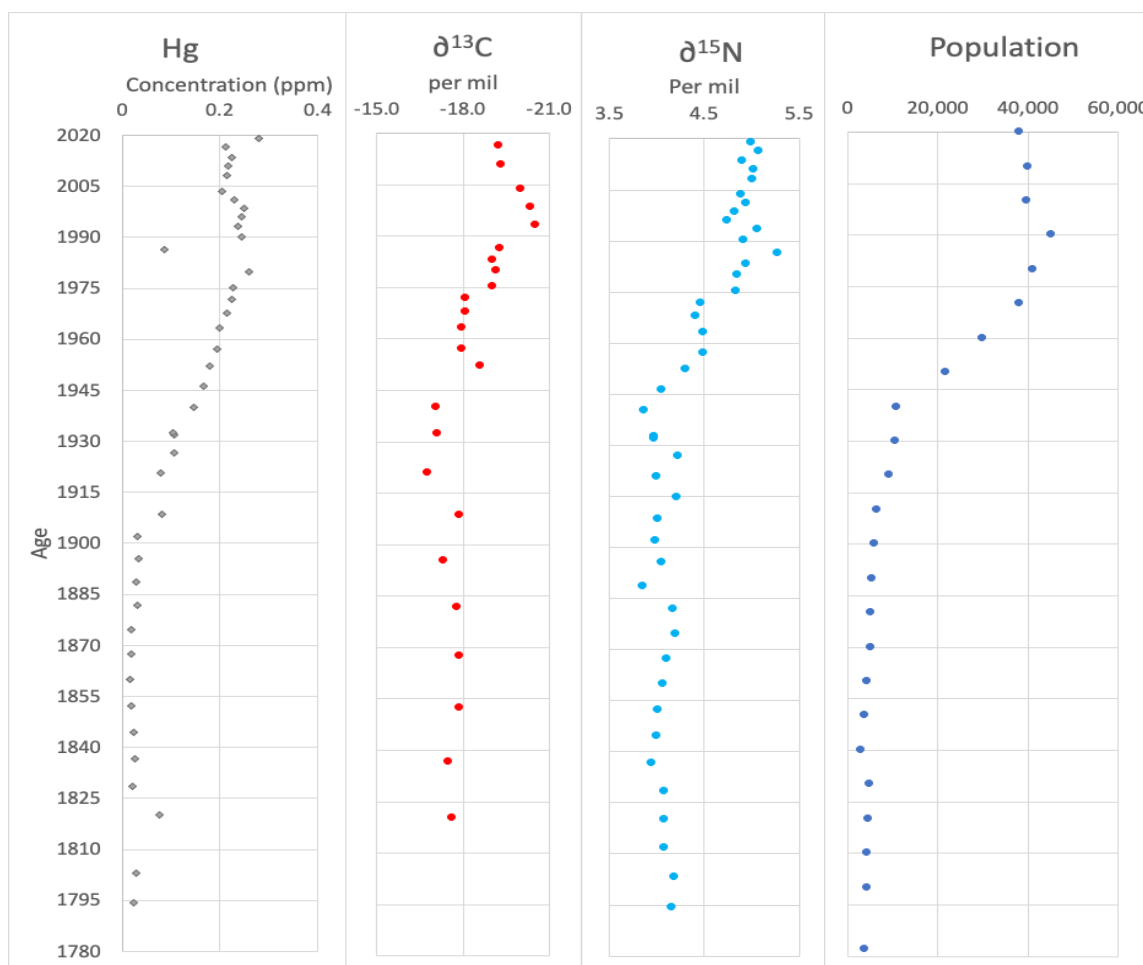


Figure 7: Graph comparing geochemical (Hg, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$, from left to right) proxies to population data. Temporal patterns of measures are all very repeatable between our metrics.

(Groton Conservation Commission, 1990) (Connecticut Department of Agriculture, 1963).

On the most local scale, zoning plays one of the greatest roles in regulating and protecting natural resources. For example, in Groton, zoning regulations dictate the amount of open area that must be retained in its natural state per lot (section 6.12-4B), and the amount of buffer that must be maintained

between water courses and adjacent stream belt wetlands, and developed land (section 6.12-4C). These guidelines and restrictions are intended to protect the quality and integrity of wetlands and water courses from specific uses and activities (Groton Conservation Commission, 1990). In summary, regulations illustrate the perceived relationship and value people place on natural resources.

Discussion

Industry

The profiles for the Mercury (Hg), Copper (Cu), Zinc (Zn), and Lead (Pb) for the Mumford Cove core are somewhat consistent with the profiles of other cores from Long Island Sound. However, their onset of concentration increase occurs later in time than in other cores and the magnitude of the shift is smaller.

The onset of Hg contamination in cores taken along the Housatonic and Connecticut Rivers occurred in the first half of the 19th Century, peaking at around 1900 and 1950–1970. Maximum concentrations for similar systems to Mumford Cove were between 250–1,500 ppb (0.250–1.5 ppm) (Varekamp J. K., 2003). Hg contamination onset our core occurred at the beginning of the 20th Century. There are no distinct or abrupt peaks in the record, and concentrations reach their maximum in the late 1970s at 0.259 ppm (Figure 4). The maximum concentration is on the lower end of what was observed in similar systems in Long

Island Sound, and the record also appears to lag temporally.

The Pb profile is temporally consistent with other cores in Long Island Sound, but the magnitude of change is a lot more muted. Pb concentrations began to rise in the mid-1930s and continued to increase until the 1970s. A core from Jordan Cove, which is consistent with others in the region, found a sixfold increase in Pb concentration between 1935 and 1975 (Benoit, 1999). This timeline is consistent with the usage of Pb antiknock compounds in gasoline. Pb concentrations appear to remain consistent following the standardization of unleaded gasoline for more than three decades. The Cu and Zn profiles for our Mumford Cove core exhibit similar relationships to other Long Island Sound records as Pb and Zn; they lag slightly temporally and the magnitude of their change appears muted (Benoit, 1999).

The muted signals of our metals data suggest our core sediments likely reflect more regional changes. The first hint for this lies in the temporal differences. In some areas of Long Island Sound basin, such as along the Connecticut River, along-river industrialization began as early as the mid-19th Century (Grant, 2014). In the case of Groton, major industry did not arrive until the beginning of the 20th Century in the form of ship and submarine yards. Most other industry, including Pfizer Inc. and the United States Submarine Base, did not begin production until the late-1940s. Since onset of metals contamination appears to occur around 1900 for Hg, it is likely atmospheric deposition may have played a role in introducing this metal to Mumford Cove. Later increases in metal contamination may reflect the ramping up of industry both in Groton and on a regional scale.

The second clue is the magnitude of change observed in our core compared to those taken at other locations in the Long Island Sound basin. The locations of other studies were often closer to areas of more intense industrial activities relative to Groton. As such, a selection of the metals we examined may actually reflect a more regional-scale signal. Since Mumford Cove is further away from large sources of some metals, the signal is relatively weak.

Ecosystem Changes

Analysis of our carbon and nitrogen proxies, $\delta^{13}\text{C}$, $\%C$, $\%N$, $\delta^{15}N$, and C: N, reveals major ecosystem shifts which coincide with both natural and

anthropogenic events. The most notable shifts occur in the 1930s–early-1940s, 1974, and between 2000–2005. Natural events include the Wasting Disease epidemic in the 1930s that decimated eelgrass beds. Conversely, or in addition, some of these periods of change coincide with rapid population growth. A larger population demands better infrastructure, which, in addition to better roads and schools, also includes wastewater treatment facilities.

Eelgrass can be used as a “canary in the mine”— it is used as an indicator for ecosystem health in systems such as Mumford Cove (Sandy, 2007). Our carbon proxies, $\delta^{13}\text{C}$, $\%C$, and C: N, are all relatively stable until the 1930s, after which all measures begin to shift. It is during this decade that Wasting Disease, a fungal infection, attacked and decimated eelgrass populations across the North Atlantic (Hartog, 1987). Following eelgrass removal from the system, $\delta^{13}\text{C}$ signal becomes more depleted and begins to trend toward more typical phytoplankton values of -21– -22 per mil. An increase in $\%C$ and decrease in C: N also occur following eelgrass removal from the system.

In 1945, a new wastewater treatment plant began discharging nutrient-rich effluent into Fort Hill Brook, the primary tributary to Mumford Cove. Excessive nutrient inflow, often referred to as eutrophication, is a condition that can lead to major physical, chemical, and biological changes. For instance, macroalgae or phytoplankton blooms, which can block light from penetrating the water column.

This makes it difficult for benthic vegetation, like seagrasses, to photosynthesize and survive (Vaudrey, Kremer, Branco, & Short, 2010).

Evidence for eutrophication can be observed in the %N and %C profiles. %N drastically increases in our profile between the late-1930s and early-to-mid-1940s (Figure 6). This reflects the increase in nutrients entering the system. At the same time, %C is also increasing, suggesting that the amount of organic carbon in the system is increasing (Figure 5). An increase in %C can be due to an increase in organic matter being brought in, produced by, or stored by the system. A natural instance where organic matter is brought into the system is if there is an influx of leaf litter, as is in the autumn. If this were the case, we would expect to observe some periodicity in our %C and $\delta^{13}\text{C}$ records, but this is not the case. The more likely explanation for the shifts in %N and %C, however, lies in the $\delta^{15}\text{N}$ record.

The enrichment in our $\delta^{15}\text{N}$ values is somewhat consistent with other wastewater records. There is a 0.5 per mil enrichment following the 1945 introduction of wastewater discharge into Mumford Cove (Figure 6). The system appears to briefly stabilize for more than a decade between 1960–1974. In 1974, a further enrichment of approximately 0.5 per mil coincides with the opening of a larger wastewater treatment facility that increased the volume of wastewater effluent. The alignment of both the original and subsequent shifts in the $\delta^{15}\text{N}$ record

and wastewater effluent introduction, allow us to draw a fairly confident relationship between the two. As such, the increase in nutrients into the system that provoked increases in both %C and %N is likely due to wastewater effluent.

Following the redirection of wastewater away from Mumford Cove in 1987, monitoring studies found that water quality returned to normal, non-eutrophic nutrient concentration within two years (French, Harlin, Rines, & Puckett, 1989). Blooms of green algae slowly dissipated, and by 1992, eelgrass was rediscovered in Mumford Cove. By 2002, eelgrasses coverage had expanded from nearly 0 to 25 hectares in a 15-year timespan since the redirection of wastewater (Vaudrey, Kremer, Branco, & Short, 2010). The upper portions of the $\delta^{13}\text{C}$ and C: N profiles reflect eelgrass recovery. The $\delta^{13}\text{C}$ values begin to drift away from phytoplankton values and are beginning to shift back in the direction of historic values (Figure 5). Similarly, C: N clearly begins to shift back toward historic levels. However, the magnitude of these shifts is not as great as the initial shifts observed following the removal of eelgrass from the system, so it appears our metrics may be more sensitive to initial disturbances than to system recovery. This could either be due to a hysteresis, or it could be an indication that the system may never return to its historic state (Duarte, Conley, Carstensen, & Sánchez-Camacho, 2009).

Cultural Shifts

Values are a central aspect of culture. They are developed and shared within a group of people and passed generation-to-generation. Over time, a group's set of values can evolve, and studying how values change can help us conceptualize dynamic shifts in culture (Dyczewski & Sławik, 2016).

A period of rapid cultural change likely occurred in the 19th Century as Groton's economy transitioned from an agricultural-mercantile base to an industrialized manufacturing tradition. The influx of industrial workers altered population dynamics by introducing a disproportionate number of young men to the community. Following this influx, there was an increase in the demand for recreational activities, such as fishing and boating, which are popular among blue-collar workers (Becker, et al., 1977). These types of activities require well-managed and maintained natural resources, likely leading to an increase in the perceived value of natural resources, such as at Mumford Cove for fishing and swimming, and Bluff Point for walking and picnicking.

Additional support for the increased valuation of natural resources over time comes in the form of grassroots movements and regulations. Local grassroots movements, such as "Save the Haley Farm" and GOSA helped mobilize the town and state to take action to protect the natural resources at Haley Farm. Their ability to raise over \$50,000 in less than 5 years through bake sales and other resident-driven fundraisers provides further support for the high value the

people of Groton attributed to Haley Farm. Furthermore, according to census data and attitude surveys conducted in the mid-1970s, more people than not favored reserving Bluff Point for conservation (Becker, et al., 1977). This stance on conservation likely extends to other natural resources, including those of Mumford Cove.

Following the foundation of the EPA and CT DEP (now DEEP), there was a general increase in the prevalence of reports and regulations focusing on the environment, natural resource management and protection. This trend may be due to an increase in awareness and/or greater importance being placed on environmental issues. A 1972 Town Planning report stated its goal was to "respond to the community's sensitivity to nature and build a strong base of environmental data on which future land use decisions could be made" (Town of Groton Planning Director's Office, 1972). A similar statement was made in the objectives of a 1974 report, which cited a "growing public awareness for the need and desirability of [open spaces]" (DEP Natural Resource Center, 1974). Since management plans and regulations must incorporate and emphasize the concerns and opinions of constituents, they provide a great insight into what the public majority values at various points in time (Becker, et al., 1977).

While the information presented thus far indicates a population that is quite environmentally conscious, this may not have always been the case. We know that the water quality in Mumford Cove

deteriorated following wastewater introduction, and despite complaints of its “spinach-soup”-like consistency and stench in the summer, not much was done to address the problem until the late-1980s (French, Harlin, Rines, & Puckett, 1989). In the 1940s, and again in the 1970s, the town approved of discharging wastewater effluent into Mumford Cove. While the 1940s decision may have been driven by a lack of knowing how this might impact the coastal environment and water quality, this does not justify the 1970s decision to build a larger wastewater plant and increase the volume of wastewater discharge into Mumford Cove. If there was opposition to the wastewater treatment plant in the 1940s, no such records were found in the Town of Groton’s archives in the History Room.

As Mumford Cove’s water quality continued to deteriorate and negatively impact recreational activities in and around it, the voices of opposition became louder. In 1985, a group of homeowners who lived adjacent to Mumford Cove filed

a lawsuit against the Town of Groton under the CWA, and they were able to win with the support of CT DEP (Sandy, 2007) (Mumford Cove Ass’n v. Town of Groton, 1986). What started as a small group of residents objecting to a eutrophied Mumford Cove resulted in the expansion of this belief, and this spread of values from individuals to a larger group of people represents a cultural shift. Following wastewater redirection, the waters slowly became clearer, and eelgrass started to return (Sandy, 2007). The return of eelgrass received mixed reactions. While environmentalists rejoiced at its return, other groups, such as recreational boaters and fishermen were initially frustrated due to equipment entanglement (Benson, 2010). However, residents of neighborhoods adjacent to Mumford Cove and others who enjoy recreational activities on its waters now recognize that clean, swimmable water, and eelgrass go hand-in hand (Sandy, 2007).

Conclusions

The goals of this study were to (i) understand whether sediment geochemistry faithfully records natural and human effects on coastal embayments, and (ii) examine the relationship between natural resource quality and the values of adjacent populations.

Results of geochemical analyses demonstrate significant correlation with anthropogenic and natural events. The

profiles of metals analyzed (mercury, zinc, copper, and lead) were consistent with previous records. Similarly, carbon and nitrogen stable isotopes, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, in addition to %C, %N, and C: N reflected changes in ecosystem state and nutrient input. However, the timing of several of the drivers examined overlap, making it difficult to draw conclusive cause and effect relationships between our data and

specific events. In addition, the metrics examined appear to be more sensitive to initial disturbances than to system recovery, as seen with both our carbon and nitrogen profiles. This discrepancy may be due to some sort of hysteresis, or these might be indicators that the system will never truly recover to its historic condition. However, it is too soon to know, and future management actions may

further influence system recovery. There is hope; based on the trend thus far regarding the relationship between humans and how they value natural resources, it appears people are taking greater care to mitigate past mismanagements and are working to ensure natural resources are preserved for future generations to enjoy.

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Appendix.

A. Aerial Photographs of Mumford Cove and surrounding area.

The white star highlights the location of the Cove across the three images, since they have slightly different frames of reference. Images courtesy of UConn MAGIC.

1934



1965



2016



B. Map of surface water drainage for Bluff Point from (DEP Natural Resource Center, 1974). It shows how land-use and management on land can directly impact Mumford Cove and its water quality through runoff.

